Fermi National Accelerator Laboratory

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Proposed Design of SAMUS Toroid and Its Magnetic Field Calculation

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I. INTRODUCTION

Presently the DØ detector has three big toroidal magnets; one Central Toroid (CF) and two End Wall Toroids (EF). The EF toroids have central openings 72" x 72". Originally this opening was meant for possible future end-plug calorimeters. Instead we are now designing Small Angle Muon Spectrometer (SAMUS) for the opening.[1)] The major component will be built at Serpukhov.[2)] The design of the toroid magnets and its magnetic field calculation is being done by exchanging information between Serpukhov and Fermilab.

II. EF TOROID

The end wall toroid iron (EF) of DØ detector is made as shown in Figure 1, where only a quadrant is shown. The thickness of the iron is 60". The coils are installed only on the vertical legs. Flux distribution inside the iron is shown. The main ring beam is going through the iron at its upper part.

Its unit coil is an eight turn coil, and four of them are installed on each vertical leg, corresponding to 16 turns per EF quadrant. The design current is 2500 Amp. This gives the field strength of 1.90~ 1.95 Teslas in the vertical leg.

III. PROPOSED SAMUS TOROIDS

Parameters of the proposed SAMUS yoke and coil are listed in Table I together with those of EF toroid.

The iron section of the proposed SAMUS toroid is shown in the first quadrant in Figure 2. The dimensions of the proposed SAMUS yoke are overall 66" wide (167.6 cm) and 68" high (172.7 cm). The center hole in the yoke is 20" wide (50.8 cm) and 23.62" high (60 cm). The center opening is 20" wide and 20" high after its coil is installed. The thickness of the yoke is 60" (152.4 cm). The gap between the vertical legs of EM and SAMUS is 3 inches due to the mechanical structure for the EF coils. The corresponding gap between their horizontal legs is now set 2" (5.08 cm) for the SAMUS coil, assuming the thickness of SAMUS coil is 4.25 cm.

The coils for the SAMUS toroid is wound only on its horizontal legs.

Any void space between these two yokes will be filled up with non-magnetic material, like stainless steel, to prevent leakage of particles.

The dimensions of SAMUS coil conductor, which was supplied by Serpukhov group, are shown in Figure 3. It has square cross section of 1.75 cm x 1.75 cm with 1 cm diameter cooling hole. With the insulation thickness of 2.5 mm, the overall dimensions of a SAMUS unit coil are 4.25 cm (1.67") high and 24.25 cm (9.55") wide. The coil's inside length is 60". We need four sets of such unit coils per SAMUS toroid and eight sets total for both SAMUS toroids.

IV. MAGNETIC FIELD CALCULATION

It is proposed to put the current in SAMUS coil in the opposite direction of that in EF coils. The detailed explanations are given in Section V, where different geometrical cases were studied.

The advantage for exciting SAMUS in the opposite current direction to that of EF is as follows.

1. Even without any exciting current for SAMUS, its yoke is already magnetized to about one Tesla, due to the non-uniform coil winding of EF.

2. Because SAMUS has coils only on the top and bottom horizontal yokes, these horizontal yokes are thinner (22.19") than the vertical yokes (23"). Therefore, we can get more uniform magnetic field in SAMUS, if we excite its current in the opposite way relative to that of EF.

The magnetic flux in the iron was calculated with POISSON of CERN version, using Fermilab VAX cluster. This version allows us up to 40,000 mesh points and calculates two dimensional field and forces. The B-H curve for 1020 steel, not anealed was used.

The flux distribution in EF and SAMUS is shown in Figure 1 with excitation currents of +2500A in EF coils and -417 Amp in SAMUS coils, corresponding to +40 and -10 kA-T/quadrant respectively.

On the x-axis and y-axis, the By and Bx components are shown respectively. In SAMUS toroid the flux distribution are quite uniform on each axis, giving By=+1.96 Teslas on x-axis and Bx=-1.85 Teslas on y-axis. In EF toroid, the corresponding flux distributions are fairly uniform but there is slight gradual decrease by 1.5 to 2% toward the outside region. These data points are shown in Figure 4, with bold points together with a case with -15kA-T/quadrant.

We can see there is some flux loop circulating around the inside conductors of EF coils, going through both EF and SAMUS yokes. Because the EF coils are placed only on their vertical yoke, the flux density in the vertical yoke is higher by 0.05 Tesla than that in the horizontal yoke at this excitation.

V. FLUX DISTRIBUTION IN SAMUS WITH DIFFERENT EXCITATION

To see the effect of SAMUS iron in EF toroid, the field distribution inside the SAMUS was calculated with different excitation current. In this study the dimensions of SAMUS are the same as those of the proposed one, except the height of SAMUS is 2" short (66" instead of 68"). The results with 0, +/-1, +/-3, +/-5, +/-10 kA-T/quadrant are summarized in Figure 4, where the EF is kept at 40kA-T/quadrant, corresponding to 2500A in EF current. The maximum flux densities in EF and SAMUS toroids on x-axis and y-axis are shown. The definition of the flux density at each location is also shown in Figure 4.

1. 0 Amp Turn Excitation

   The field distribution with 0 Amp excitation in SAMUS coil and 2500 Amp in EF coil is shown in Figure 4. Due to the excitation field from the EF coil, the SAMUS iron is magnetized as shown. Its magnetic flux direction in iron is opposite to that in EF iron.

   The average flux density in the SAMUS iron is 1.1 Teslas. This is expected because the magnetic field next to EF coils is about 350 Oersteds.

2. +/- 1KA-T/Quadrant Excitation

   There are two different directions to excite the field coils of SAMUS coils. If we want to utilize the effect of the EF coils, the current directions in the outer SAMUS conductor is same as that of the inner EF conductor. The results of field calculation is shown in Figure 4 with -1kA-T/quadrant excitation. Its magnetic flux direction is opposite to that in the EF iron. The maximum flux density in the yoke is +1.62 and -1.36 Teslas on x- and y-axis respectively.

   If we excite the SAMUS coils in the opposite direction, its magnetic flux flow direction is same as that of EF iron. The result is shown also in Figure 4 with +1 kA/quadrant excitation. The maximum flux density is -1.18 and +1.58 Teslas on x- and y-axis respectively.

3. +/- 10KA-T/Quadrant Excitation

Similar calculation is done with +/-10kA-T quadrant. The resulting magnetic field distributions are shown in Figure 4. The maximum flux density in the iron is +1.94 and -1.89 Teslas for -10kA-T and -1.49 and +2.08 Teslas for +10kA-T on x- and y-axis respectively.

4. Forces on SAMUS Iron

4.1 Cases with Negative Current Excitation

The two-dimensional force calculation in a quadrant shows that the SAMUS iron will be pulled toward the EF iron with the negative current. This will cause the side-way and vertical motion if there is some asymmetry in left and right gaps and top and bottom gaps. Therefore, some clamping of the SAMUS irons in horizontal and ventrical direction is needed.

4.2 Cases with Positive Current

In this case, the forces on the SAMUS iron is toward the center of the coordinate. In two dimension, this force will move the SAMUS toward the central stable point.

References:

1) D. Green, et al, DØ Note 398, 1986.
Magnetized Insert Plug Proposed

2) Institute of High Energy Physics, Serpukhov, DØ Note 679, March 11, 1988.
Small Angle Muon Spectrometer

TABLE I PARAMETERS OF EF AND PROPOSED SAMUS TOROIDS

	EF		SAMUS PROPOSED	
YOKE	(IN)	(CM)	(IN)	(CM)
Overall height	328"	833.2	68"	172.7
Overall width	328"	833.2	66"	167.6
Thickness	60"	152.4	60"	152.4
Hole width	72"	182.8	20"	50.8
Hole height	72"	182.8	23.62"	60.0

COIL/EF OR SAMUS TOROID	EF	SAMUS PROPOSED
No. of unit coil	8	4
No. of unit coil/ quadrant	2	1
Turn/unit coil	8	24
Amp-Turn/quadrant	+40kA-T	-10kA-T
Total amp-turn	+160kA-T	-40kA-T
Current	2500A	-417A
B in yoke (T)	By(y=0)=-1.97~1.93 Bx(x=0)=+1.92~1.89	By(y=0)=+1.96 Bx(x=0)=-1.85
Resistance		4x7.9mΩ=31.6mΩ
Voltage		4x3.3V=13.2V
Wattage		4x1.38kW=5.5kW
PS		18V,500A (HP 6466C)

NOTE: TOTAL NUMBER OF SAMUS UNIT COILS IS 8, AND WE NEED TWO POWER SUPPLIES.

Fig. 1 Flux Distribution in EF and SAMUS

Run: EFSA 6.1;1

EF COIL +40 kA-T/Quad

SA COIL - 10 kA-T/Quad

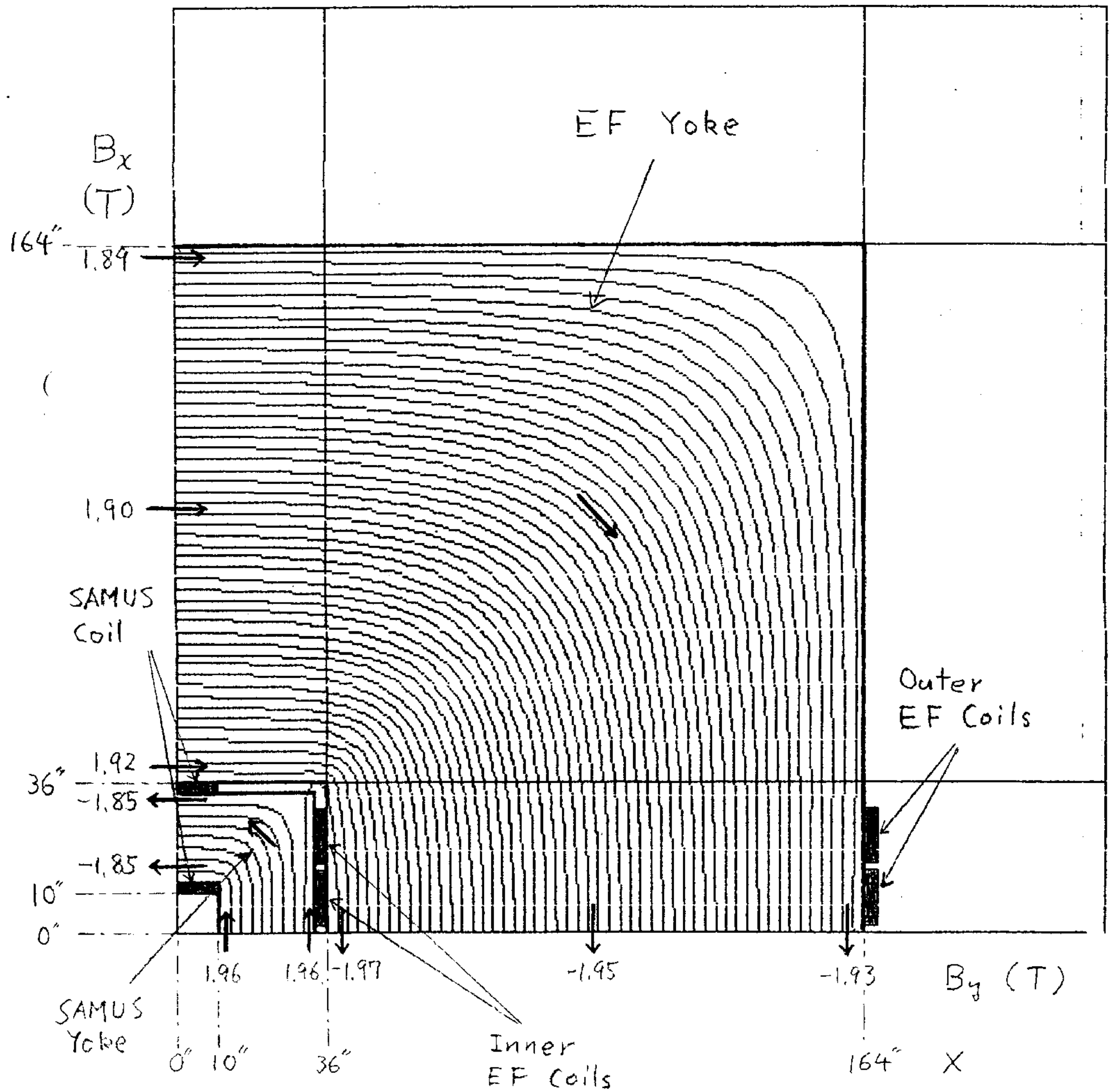

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Fig. 2 Proposed SAMUS Geometry

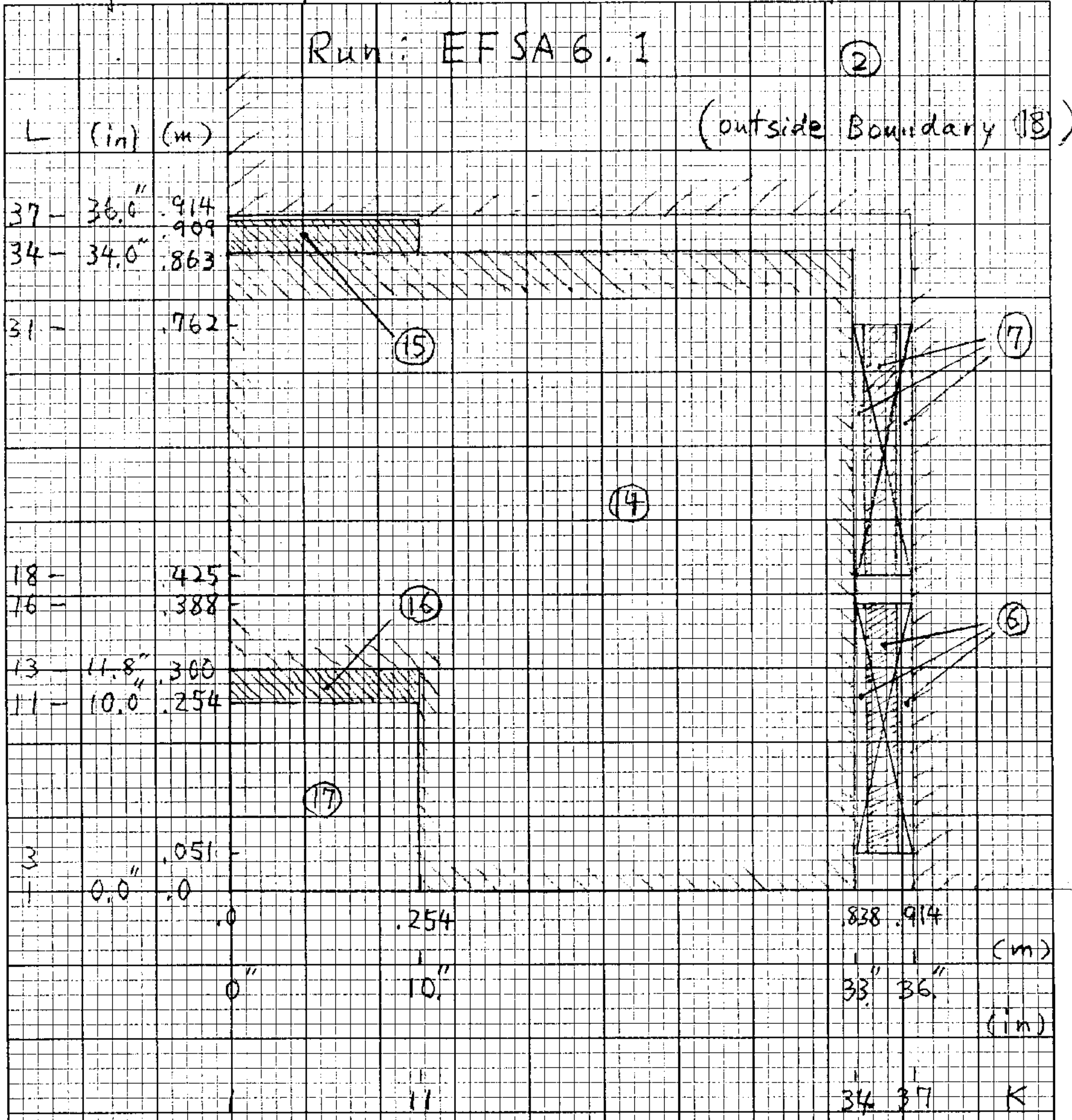

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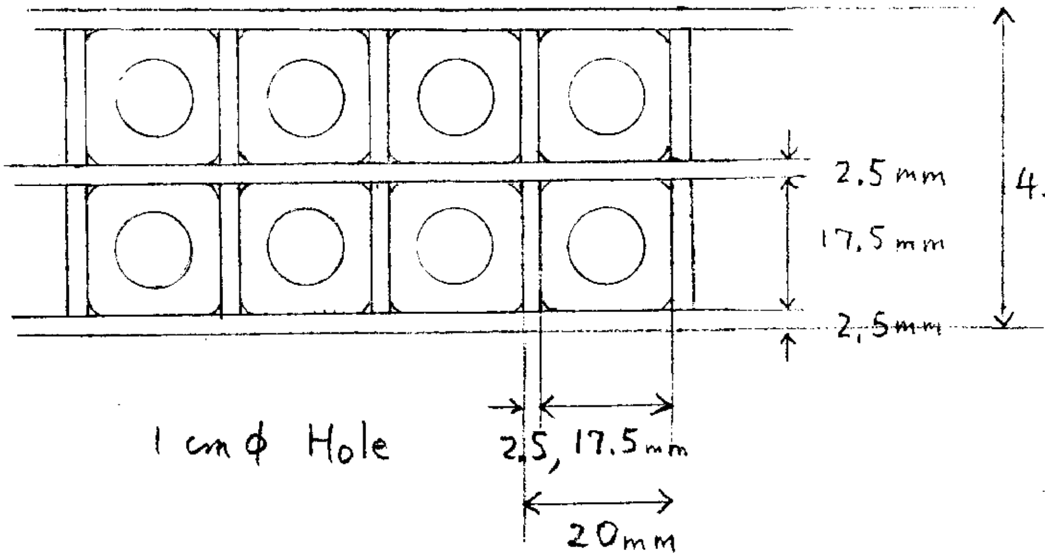
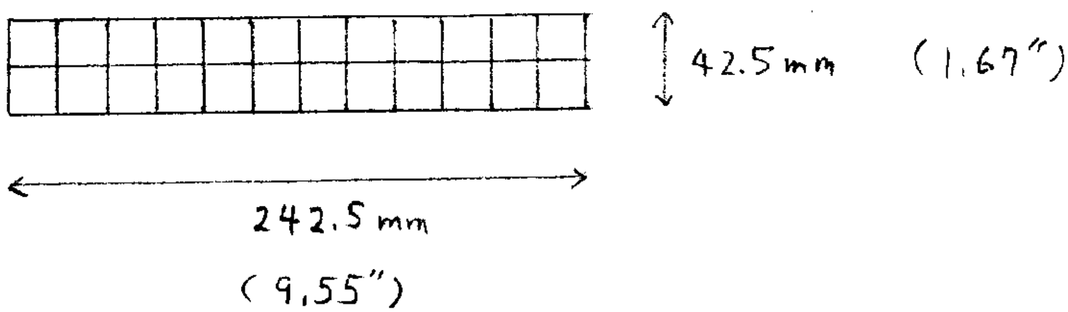
Fig. 3 SAMUS CONDUCTOR



Coil Cross Section



4 sets of Coils / SAMUS Toroid

Total 8 sets of Coils needed

Amperage

$$\frac{10{,}000}{24} \text{ AT/Quad} = 417 \text{ Amp}$$

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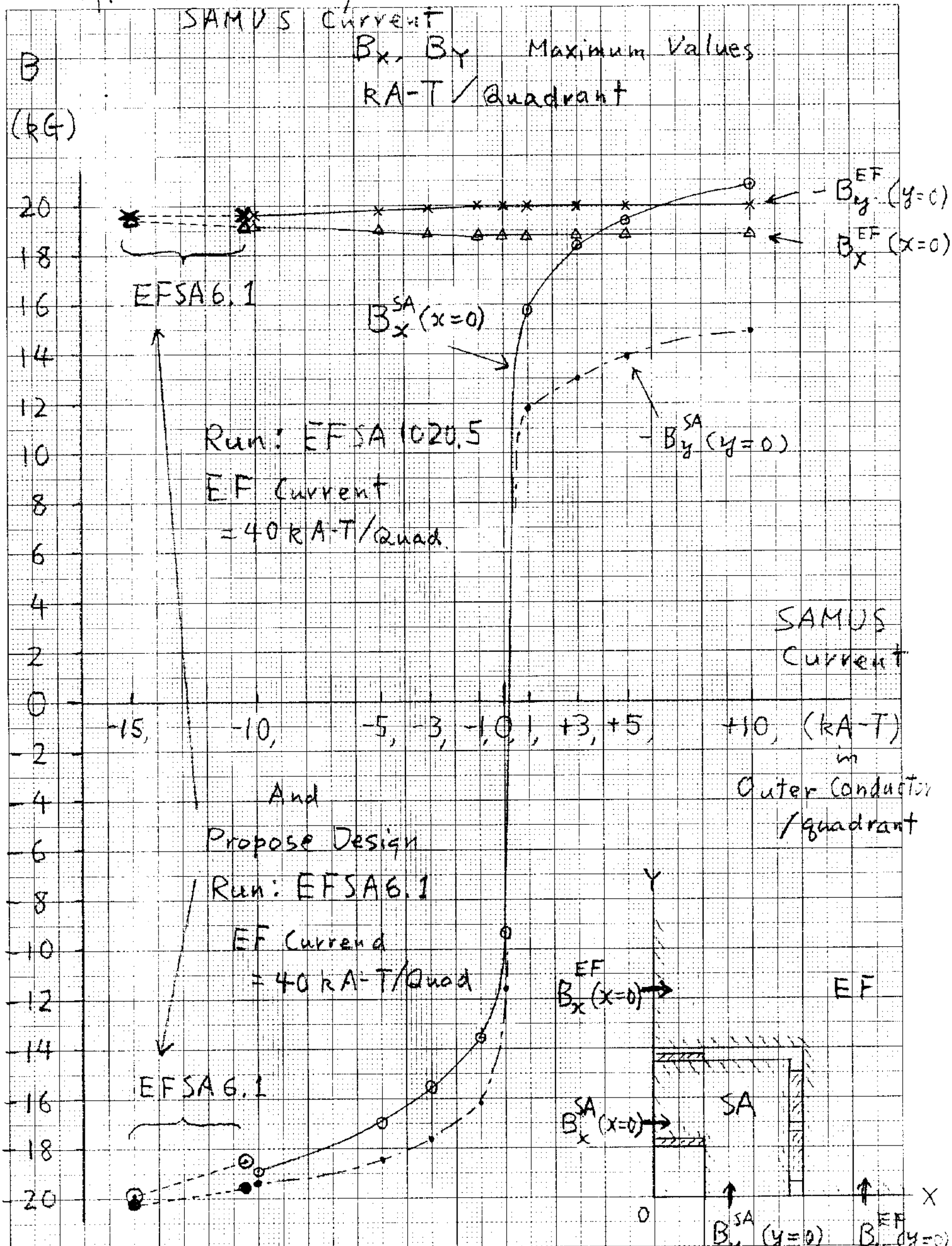
Fig. 4 Flux Density in EF & SAMUS with Different SAMUS Current



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